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Citation: Journal of Vacuum Science & Technology B 16, 3142 (1998); doi: 10.1116/1.590453
View online: http://dx.doi.org/10.1116/1.590453
View Table of Contents: http://scitation.aip.org/content/avs/journal/jvstb/16/6?ver=pdfcov
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Extreme ultraviolet lithography

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(Received 29 May 1998; accepted 16 September 1998)

An extreme ultraviolet (EUV) lithography tool using 13.4 nm radiation is being developed by a consortium of integrated circuit (IC) manufacturers to support 100 nm imaging for integrated circuit production. The 4×, 0.1 NA alpha tool has a >1 μm depth of focus, all reflective optics, a xenon laser plasma source, and robust reflective masks. The technology is expected to support feature scaling down to 30 nm. © 1998 American Vacuum Society. [S0734-211X(98)12006-1]

I. INTRODUCTION

Although the first papers proposing the use of extreme ultraviolet (EUV) or soft x-ray radiation (wavelengths from 2–50 nm) for projection lithography were published in the late 1980's,1-4 extensions of conventional optical lithography have continued to dominate semiconductor device manufacturing. These extensions have relied on incremental decreases in illumination wavelength and increases in optical numerical aperture (NA) for the system. While 248 and 193 nm optical lithography can be extended to support integrated circuit (IC) manufacturing for 130 nm and perhaps 100 nm, a next generation lithography technology will be required for printing <100 nm features. Extreme ultraviolet lithography (EUVL), using 10–14 nm extreme ultraviolet light, is one of the most promising technologies. This technology builds on the industrial optical experience, uses an EUV light source, and is initially expected to support IC fabrication at 100 nm; scaling is expected to support several technology generations down to possibly 30 nm.

The two fundamental relationships describing a lithography imaging system, resolution (RES) and depth of focus (DOF), are given by

\[ \text{RES} = k_1 \lambda / \text{NA} \]  
(1)

and

\[ \text{DOF} = k_2 \lambda / (\text{NA})^2 \]  
(2)

where \( \lambda \) is the wavelength of the radiation used for imaging and \( \text{NA} \) is the numerical aperture of the camera. The parameters \( k_1 \) and \( k_2 \) are empirically determined and correspond to those values that yield the desired critical dimension (CD) control within an acceptable IC manufacturing process window. Values for \( k_1 \) and \( k_2 \) of 0.6 and greater have been used in high volume manufacturing, however, a given lithographic technology can be extended further for smaller values for \( k_1 \) by optimizing the IC fabrication process at the cost of tighter process control. Setting \( k_1 \) and \( k_2 \) equal to 0.5 corresponds to the theoretical values (Rayleigh criteria) for resolution and DOF.

Equations (1) and (2) demonstrate that improvements in resolution achieved by incremental decreases in wavelength and increases in NA result in a decrease in DOF and corresponding decrease in the process window. EUVL extends optical lithography by using much shorter wavelengths rather than increasing NA to achieve better resolution. As a result, it is possible to simultaneously achieve a resolution of 100 nm or smaller and a DOF of 1 μm or larger by operating with a wavelength of 20 nm or less using a camera having a NA of 0.1 or less.

Despite the potential advantages of shorter EUV wavelengths, the continued extension of optical lithography and the technical challenges associated with using EUV radiation as a light source have delayed industry acceptance and investment in the technology. Most of the research and development in the US during the early 1990's were performed by the Department of Energy and AT&T Laboratories. In 1996, changes in government funding priorities resulted in reduced support for the Department of Energy (DOE) EUV program at Lawrence Livermore National Laboratory and Sandia National Laboratories.

Based on the technical success of the DOE program and the potential of EUV lithography to be scaled to small geometries, a consortium of semiconductor manufacturers, the EUV LLC, was formed in 1997 to provide funding and guidance for the commercialization of EUVL. The EUV LLC consortium is composed of Advanced Micro Devices, Intel, and Motorola. The program goal is to facilitate the research, development and engineering to enable the Semiconductor Equipment Companies (SEMs) to provide production quantities of 100-nm-EUV exposure tools for IC manufacturing by 2004.5 Funding is provided by the EUV LLC to the (DOE) Virtual National Laboratory (VNL) composed of Lawrence Berkeley National Laboratory (LBNL), Lawrence Livermore National Laboratory (LLNL), and Sandia National Laboratories (SNL) to perform the required research and engineering. Joint development programs support key EUV component technologies with industry partners. The LLC members are also investing resources within their own companies to support mask and resist development.
II. OBJECTIVES

The objectives of the EUV LLC program are to extend and apply the basic technology to the design, fabrication, and testing of an alpha-like tool denoted as the Engineering Test Stand (ETS) and to transfer learning to the SEMs for the development of beta tools. The beta tools are expected to result in production tools for 100 nm geometries by 2004.

The EUV program represents a highly parallelized program focused on the phased development of the (1) alpha, (2) beta, (3) production tools, (4) simultaneous support for masks and resists, and (5) establishment of an industry infrastructure for EUV specific component development. The program relationships are shown in Fig. 1.

The following discussion outlines the ETS tool design development approach, some of the specifications associated with the subsystems, and technology and component development status. Early EUV printing results are obtained using existing 10X microsteppers. Finally, a few of the potential advantages of the EUV technology for the next generation lithography applications are listed.

III. TOOL DEVELOPMENT STRATEGY: ENGINEERING TEST STAND

The goals for the ETS are focused on continued technology development, integration of the technology into a tool, and transfer of the technology and learning to the stepper companies for the beta tool development. The program is not focusing on demonstrating technology elements, which are extensions of current optical lithography steppers, such as precision alignment and wafer handling, which are expected to be implemented in a commercial EUVL tool. With input from the end users including both the semiconductor manufacturers and the stepper companies, the ETS will serve to significantly lower risk in EUV-specific areas including source, condenser, reticle, projection optics, environmental system, and methods for isolating the environments and eliminating contamination.

The ETS development will provide a flexible test stand for EUV-specific system, subsystem, and component learning. This machine will initially emphasize EUV flux throughput, not wafer throughput, will have simplified wafer handling, and a simplified software and user interface. It will be heavily instrumented with diagnostics to provide as much performance learning data as possible.

A schematic representation of an EUV lithography tool is shown in Fig. 2. The key EUV technologies include: (1) an EUV illumination system consisting of a radiation source and a condenser system to collect the light and to provide proper ring field illumination, (2) a patterned reflective mask, (3) a 4X reduction camera using four mirrors, (4) multilayer coatings for optical elements and masks, (5) an EUV sensitive resist, and (6) metrology to support manufacturing and inspection of reticles. Non-EUV specific subsystems consist of the focus and overlay systems, scanning mask and wafer stages, optics housing, and wafer and reticle handling interfaces and robotics. A preliminary structural and mechanical design based on CAD drawings is shown in Fig. 3.

The ETS is based on a laser plasma point source and a four mirror, ring-field imaging system. A single membrane filter separates the condenser from the mask and projection optics. With four mirrors, the reticle and wafer stages can be located on either side of the projection optics box, eliminating interference problems associated with mechanical scanning. EUV flux to the wafer will support a throughput of...
approximately ten (300 nm) wafers per hour. A comparison of high level specifications for the ETS and a beta EUVL scanning system is given in Table I.

### A. System design considerations

To minimize the risks in implementing the complex system, a structured implementation approach has been followed which includes: (1) detailed program planning accounting for all project development tasks and interdependencies, (2) extensive use of computer modeling for all design activities including system mechanical, thermal, and structural properties, and (3) application of proven components and subsystems existing in present scanning lithography tools and EUV microsteppers. The following sections address some of the requirements and challenges associated with key subsystems.

### B. Source

The EUV source must provide sufficient power at the desired wavelength to yield an adequate wafer throughput for a lithography tool. EUV photons can be produced by a variety of sources including laser-produced-plasma (LPP), synchrotron radiation, high-harmonic generation with femtosecond laser pulses, discharge-pumped x-ray lasers, and electron-beam driven radiation devices. Most of these methods cannot achieve the required output of 30–60 W of EUV source power at acceptable manufacturing costs for production lithography equipment and only the first two have been used for EUV development to date.

Synchrotrons are well-developed, clean, highly reliable, and have been successfully used as sources for x-ray lithography and early EUVL demonstrations. A proposed design optimized for EUVL applications and using bending magnet radiation was published in 1993. This design supported a maximum ring current of about 500 mA with the projected useful power emerging from an appropriate beam line condenser being about 250 mW, a factor of 4–10 smaller than required for adequate printing speed. Although a single synchrotron could supply radiation to multiple steppers, synchrotrons require unique and costly facilities. Optimized synchrotron sources may be developed in the future, however, present EUVL tools focus on using a compact LPP source.

The LPP sources are formed by focusing a pulsed laser beam onto a solid, liquid, or gas target to produce a bright “spark” which has broad emission from the visible to the EUV. Solid metal sources produce a great deal of debris in the form of particulates and condensable metal vapor. To avoid the debris problem, a target using fully recycled clusters of xenon in a supersonic jet has been developed; this source has been selected for the ETS and is shown in schematic form in Fig. 4.

The LPP produces a point-like source converting 0.8%–3.8% of the incident laser power into EUV light in the required spectral bandwidth. Due to the small (∼200 μm) source size, condensers have been designed that have a geometric collection efficiency of ∼30% and deliver the in-band radiation to the mask of a scanning ring-field projection optic. High-repetition-rate (>3000 Hz) pulsed laser drivers that deliver 1500 W average power to create the Xe plasma are actively being developed commercially. Condenser reflectance loss from source particles, an issue in earlier laser plasma sources with metal targets, has been eliminated using the gas cluster targets. The cost and complexity of the integrated laser and Xe light source system is high compared with conventional light sources employed in current lithographic equipment, but is expected to be reduced with further development.

### C. Condenser

The condenser is a complex optical system that collects EUV power from the 200-μm-diameter source and conditions the light to uniformly illuminate the mask and to properly fill the entrance pupil of the camera. For the system shown schematically in Fig. 2, the condenser is formed of six separate collection channels. The first element of the condenser is a steep, aspheric, ML-coated mirror that captures about 30% of the EUV radiated by the LPP source. Water cooling will be employed to remove heat due to out of band radiation absorbed by the MLs. Because of the large collection angle, the mirror has graded ML coatings (i.e., coatings with thickness varying as a function of the angle of incidence). The remaining condenser optics use near normal and grazing incidence mirrors to image the spherical source onto the ring field at the mask. Each of the six channels fills the entire ring field and a portion of the camera entrance pupil. When all the channels are summed, every field point is identically illuminated and the camera entrance pupil has an effective fill factor of the desired value (typically, $\sigma = 0.7$).

The condenser uses critical illumination in the scan direction (i.e., the radial direction) and Kohler illumination in the cross-scan direction.
focus of a ring-field cord length of 26 mm at the wafer; mechanism for the beam, and must be less than 0.1 nm rms.

shorter wavelengths of light are used for lithography, since tended to be dark. This scattering is called flare. The delete-bright regions in the image plane into regions that are in-light that reduces image contrast, i.e., scattering of light from frequency roughness, contributes to near-angle scattering of wavelengths greater than 1 mm. Errors having shorter wavelengths are classified as mid-spatial or high-spatial frequency roughness. Stringent requirements must also be discussion, surface figure error is described by errors having spatial wavelengths greater than 1 mm. Errors having shorter wavelengths are classified as mid-spatial or high-spatial frequency roughness. Stringent requirements must also be placed on surface roughness. Roughness having wavelengths in the range from about 1 mm–1 μm, called midspatial-frequency roughness, contributes to near-angle scattering of light that reduces image contrast, i.e., scattering of light from bright regions in the image plane into regions that are intended to be dark. This scattering is called flare. The deleterious effects of flare are becoming more evident as ever shorter wavelengths of light are used for lithography, since scattering is proportional to 1/λ². In order to keep these effects manageable, the midspatial-frequency roughness must be less than 0.2 nm rms. High-spatial frequency roughness (periods of 1–0.02 μm) cause hight angle scatter, a loss mechanism for the beam, and must be less than 0.1 nm rms.

The four-mirror design shown in Fig. 5 was selected be-cause the ray angles of incidence on each mirror could be made low enough to allow a uniform multilayer coating. This substantially reduces the risk in the multilayer coating process where spectrally matched, uniform coatings are required. The aspheric departure for each mirror substrate is also only a few microns which reduces the risk associated with optical fabrication and metrology. The image static distortion was constrained so that the dynamic (or scanned) distortion is dramatically reduced, e.g., the static distortion of the design is approximately 15 nm while the dynamic distortion is less than 1 nm.

Magnification can be adjusted by simple translation of the mask and wafer; no adjustment in the optical package is required. For example, an axial motion of the mask by 8.9 μm results in a 1 ppm change in magnification.

2. Multilayer coating technology

The ML mirrors must meet stringent performance and throughput requirements for a production EUV projection lithography system to be practical. Initial lithography system throughput analysis and cost-of-ownership estimates have led to goals for stable multilayer mirrors with 68% or higher reflectance.

Mo/Si multilayers (ML) with a reflectivity peak at 13.4 nm wavelength have been selected for the ETS. The ML structure consists of a stack of 81 alternating layers of Mo and Si with individual layer thicknesses around 2.8 nm for the Mo and 4.0 nm for Si. These thicknesses were determined by maximizing the constructive interference of the beams reflected at each interface and minimizing the overall absorption to enable more interfaces to contribute to the reflectance. The resulting ML structure resembles a quarter-wave stack in which the relative thickness of the Mo layers has been slightly reduced.

The optimum deposition conditions of the Mo/Si multilayer system have been established and reflectances around 68% are routinely achieved. Figure 6 shows the near-normal incidence reflectance of a Mo/Si multilayer mirror deposited in a dc-magnetron sputtering system. Although
Mo/Si has been selected for the ETS, Mo/Be coated mirrors may be used for the beta tool to optimize the EUV collection from the LPP source.

Mo/Si MLs optimized for maximum reflectance typically have a stress of $-350$ to $-400$ Mpa (compressive). This level of stress is high enough to provide angstrom level deformation of the figure of the precision optical substrates for the projection optics. Two approaches are used to mitigate the deformation: (1) reduce the film stress so the resulting deformation is negligible; or (2) use the compensation capability of the optical design to correct the stress-induced deformation. The present strategy is based on techniques that anneal the films or manipulate composition. A Mo/Si ML can be produced with essentially zero stress with a 1.0% loss in reflectivity by annealing or no reflectivity loss by applying a buffer layer to negate the stress.

3. Alignment/overlay

Many factors affect the total overlay including thermal control of the reticle, reticle pattern placement, reticle flatness, optical distortion, stage precision, and reticle-to-wafer alignment sensors.

Thermal modeling results have identified temperature control of the reticle as an issue that needs more detailed attention. These calculations assume that the reticle substrate material is silicon. Radiation-induced heating, at throughput rates of commercial interest, will cause overlay errors, unless thermal control is implemented. Various approaches to reticle thermal management are being formulated including the use of a low expansion material for the mask substrate and active cooling.

Reticle flatness impacts overlay for reflective reticles because of non-telecentricity at the reticle. To illuminate reflective reticles, the projection system must be designed with the chief rays at an angle to the reticle normal (i.e., non-telecentric). For a chief-ray angle of $5^\circ$ to the reticle normal, the calculated flatness requirement is $\pm 0.2 \mu m$ over the ring field illumination area. This flatness specification is well within the state of the art in optical fabrication, and does not present a significant issue in overlay control for EUVL. A mask flatness deviation of 100 nm results in an image movement of 2.5 nm.

Overlay errors due to distortion in the projection optics system can arise due to fabrication errors in the mirror substrates. Extremely tight figure tolerances must be achieved in the aspheric mirror substrates to reduce wavefront error to acceptable levels. If these tolerances are achieved over the clear apertures of each mirror, image distortion will also be reduced to acceptable levels.

Other contributors to overlay errors and alignment methods are similar to those of other DUV step-and-scan systems. The ETS utilizes magnetically levitated reticle and wafer stages with precise control to satisfy the scan distortion specifications and direct and indirect sensing for reticle to wafer alignment.

4. Thermal loading

Since 25%–35% of the incident EUV radiation is absorbed by each multilayer coated optical element, the effect of thermal loading on the optical performance of an EUV projection optics system must be understood. Extensive thermal modeling has been completed for the ETS optical system to predict performance under various throughput conditions. Time-dependent three-dimensional thermal and structural transient finite element analysis (FEA) was performed for the ETS under the condition of continuous illumination, for ten wafers (300 nm) per hour throughput, over a 14-h period with radiative cooling as the only heat transfer mechanism. This boundary condition represents a worst case scenario.

The predicted change in surface shape for each mirror was incorporated into optical and lithographic codes to determine the effect on system performance. The dominant behavior was found to be a negligible focal shift of 0.14 $\mu m$ during the first 30 min of illumination. This falls easily within the process window depth of focus. The low NA aspheric EUVL optical system is extremely tolerant to changes in optical element’s base sphere (typically $\pm 50 \mu m$) caused by heating. Focal shifts due to system warmup are common in current optical steppers or step and scan machines. No significant field distortion, arising from any aspheric thermal distortion, occurs.

E. Environment

The vacuum environment required for EUVL presents challenges in component design, thermal management, contamination control, and wafer and reticle handling. All internal components must be designed for vacuum compatibility in two respects. First, the system must operate in vacuum with little or no lubrication. Second, the system must not contaminate the optics with outgassing products.

Convective heat transfer is limited in the EUVL vacuum environment of a few tens of mTorr. Radiative and conductive heat transfer must be utilized as a primary means of thermal management. Thermal modeling is being used to evaluate structural and vacuum enclosure components with respect to heat transfer issues.

Contamination of the EUV environment by carbon-containing gases must be strictly controlled. EUV photons can crack the carbon-containing gases, releasing carbon, which adheres to the mirrors, reducing the reflectivity and photon throughput of the system. These species cannot be completely eliminated because of resist volatiles. While carbon can be cleaned off of mirrors without damage, the scheduled maintenance interval must meet operational requirements. Several approaches to environmental management are being explored. One strategy uses low pressure directed gas flow to continuously maintain a super-clean environment in the EUV path at the wafer.

The use of the low power mag–lev stages further minimizes contamination by avoiding contacting surfaces and the need for lubricants.
IV. PROCESS WINDOW SIMULATIONS

A significant advantage of a low numerical aperture EUVL optical system is that an illumination system with fixed sigma can easily be utilized for both dense and isolated features. Simulations have shown that a good depth of focus can be realized simultaneously for 0.1-μm-Iso/Dense features (refer to Fig. 7). A small amount of mask bias (7 nm) between iso and dense features is required to ensure a process latitude of ±7% over a 1.0 μm depth of focus.

A. Masks

The EUV mask consists of a high reflectance multilayer coated substrate with a patterned absorbing overlayer (metal layer). The silicon wafer substrate has the surface smoothness required for the EUV application and can be processed using the advanced wafer fabrication capability established by the semiconductor industry.

The EUV Mo/Si ML mask blanks for 13 nm consists of 81 alternating thin film layers of Mo and Si. A 4-nm-Si capping layer is added to prevent oxidation of the Mo on exposure to the atmosphere. Optimum optical properties are obtained when the individual layers are smooth, the transition between the different materials is abrupt, and the layer to layer thickness variation is maintained within 0.01 nm. ML deposition on 150-mm-silicon wafers for EUV mask blanks has been demonstrated using techniques such as magnetron sputtering, ion beam sputtering, and LPCVD.

The challenge for EUV mask blank fabrication is defect reduction. This effort has focused on producing ultraclean wafer substrates for ML deposition, developing an ultraclean ion beam sputtering deposition system and processes, and inspecting defects on the blanks. Since the repair of any ML defect is impractical, “defect free” blanks (very low defect density such that the probability of defects coinciding with the critical area of the circuit is very small) are essential. In the past few years, the ML defect density on a 150 mm wafer has been drastically reduced from an initial level of 10^5/cm² down to the current level of <0.1/cm² for defect sizes >130 nm. The coating uniformity across a 150 mm wafer has been improved from 5% to 0.8%. The goal is to achieve a ML defect density of 0.01/cm² by the year 2000 and 0.001/cm² for defect sizes >30 nm by the year 2004 on 300 mm wafers.

The EUV masks are patterned using conventional silicon wafer processing. An absorbing layer (Al, Ti, or others) is deposited on the ML wafer blanks and patterned using optical exposure or e-beam direct write methods. Optical or e-beam inspection of the patterned wafer leverages existing and emerging inspection equipment, such as KLA StarLite™ and SEMSpec™ inspection tools, while at-wavelength inspection is being developed. One of the key advantages of using wafers for EUV masks is the continuous improvement of advanced wafer processing equipment and materials.

The mask processing capability has been demonstrated by fabricating a small field EUV mask using current wafer processing facilities. This mask has been tested in a 10× microstepper exposure system where 100-nm-dense lines and 70 nm isolated lines with 0.6-μm-thick TSI resist have been demonstrated with very good profile integrity as shown in Fig. 8.

B. Resists

Specific demands on the EUVL photoresist arise due to the strong attenuation of the 13.4 nm radiation in virtually all organic resist materials. The absorption is atomic in nature and depends only on the chemical composition (no dependence on molecular bonds) and density of the absorbing medium. Because 13.4 nm light is so strongly attenuated in all organic materials, a thin layer imaging (TLI) process will have to be used. For throughput considerations, it is estimated that the required dose for this TLI process will need to be approximately 10 mJ/cm², suggesting that chemically amplified resists are necessary. A limit on the line edge roughness is estimated to be <5 nm to control CD variation at the desired resolution of 100 nm. The thickness of the pattern resist must be greater than 0.3 μm, but probably less than 0.6 μm, and the sidewall angles are expected to be at least 85°. Finally, like e-beam resists, the EUVL resist will have to be stable in a vacuum.

Several TLI processes have been identified for potential EUVL use. The common theme in these approaches is the creation of an image in a thin layer of refractory-containing material, which is then used as a dry O2 etch mask during a subsequent pattern transfer to the device layer. The refractory material will in all likelihood contain silicon, which provides a SiO2 etch mask in the O2 etch process. All of the TLI schemes could be a positive or negative tone depending on

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**Figure 7.** Exposure–defocus plot for 0.1 μm iso/dense features.

**Figure 8.** 70 nm lines (1/2) printed in 600 nm of resist using absorber mask.
the exact materials and process steps used, but positive tone is preferred if only a single tone proves feasible. It is easier to print via holes and other small features with positive tone processes.

V. METROLOGY

High accuracy metrology tools are prerequisites for fabricating the precision optics for EUVL. Commercial tools (such as the atomic force microscope) are readily available for the measurement of surface roughness to the levels required. Improvements in figure metrology have been made that will enable the absolute measurement of surfaces to the accuracy required. The first of these innovations is the “Sommargren interferometer” which has demonstrated surface figure measurement accuracies <0.25 nm rms. This interferometer utilizes visible light and is in use in optical fabrication facilities for the fabrication of the EUV mirror substrates. Since the optical system must be characterized after the optics are coated with ML reflectors, measurement of the final assembled optical system wavefront error will be performed using light at the wavelength of intended operation. An EUV interferometer has been developed which will be used to characterize the final wavefront quality of the entire camera and make final adjustments as needed. Further metrologies include precision reflectometry and at-wavelength scattering, which provide diagnostics for multilayer coating development, optical system throughput evaluation, and scatter as it affects wafer plane contrast. Figure 9 summarizes the at-wavelength metrologies for EUV lithography.

VI. 10× MICROSTEPPER

Two existing EUVL microsteppers are being used by EUV LLC to address a number of system issues. The 10× microsteppers serve as near-term integration test beds and development tools for: clean laser plasma sources, EUV projection optics performance, in situ aerial image monitoring, reticle-to-wafer alignment, in-vacuum focus systems, a maglev wafer stage, vibration isolation, wafer-based masks, resist development, EUV membrane filters, dose monitoring, and control software development. Typical EUV images of 80 nm lines and spaces in 600 nm of resist using the 10× microstepper are shown in Fig. 10. Imaging experiments have been performed using the 10× microstepper to experimentally determine the DOF latitude.
and exposure process linearity for a TSI resist with DMDS processing. The results are shown in Figs. 11 and 12. As noted, the results show $\pm 2 \mu m$ DOF at $\pm 5\%$ CD and perfect linearity from 200 to 80 nm.

VII. ADVANTAGES OF EUV

There are several advantages of EUV lithography over the other candidate technologies. EUV parallels and builds on the conventional optical lithography experience base: (1) imaging follows the relationships of conventional optics for resolution and depth of focus as a function of NA and is expected to scale down to 30 nm; (2) the robust 4× masks are easier to write than 1× masks and do not use fragile membranes or segmented membrane masks and use conventional silicon processing to define the final geometric patterns on the mask, (3) the use of low NA optics provides good depth of focus and linearity for isolated and dense structures simultaneously, eliminating the need for optical proximity or phase shift correction; (4) the technology provides a granular tool solution when the laser produced plasma is used; (5) photoresists used by 193 or 248 nm are potentially extendable to EUV wavelengths; (6) the technology is fully compatible with larger circuit design rules and could be introduced selectively at 130 nm, and (7) wafer throughput values of >40 wph (300 mm wafers) are possible using current designs and component technologies.

Successful implementation of the EUV technology will allow IC makers to work with light of wavelength 20 times shorter than today’s deep ultraviolet technology (248 nm). These shorter wavelengths, in turn, allow a return to low numerical aperture optical imaging systems, which provide high resolution and large depth of focus without the need for reduction in $k$ factors. It is anticipated that EUV lithography will allow feature sizes on chips to be reduced from 0.25 to 0.1 $\mu m$ and below. These advances will enable the speed and memory as well as power, reliability, and cost-effectiveness of computer ICs to improve as the linewidths (feature sizes) on the chips shrink in size.

ACKNOWLEDGMENTS

The EUV LLC consortium wishes to acknowledge the large number of dedicated scientists and engineers located at the DOE National Laboratories within the VNL, the consortium partners, and component and exposure tool suppliers that have contributed to the work reported in this article and to the continued development of EUVL.

5Extreme Ultraviolet Lithography, a white paper prepared by Charles Gwyn et al., EUV LLC, Sept. 1997.